

FINAL TECHNICAL REPORT
September 1, 1997, through June 1, 1999

Project Title: **EFFECTS OF CHLORINE IN COAL ON FURNACE WALL CORROSION UNDER LOW-NO_x CONDITION**

ICCI Project Number: 97-1/4.1B-1
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ABSTRACT

British literature published since the late 1960s has shown accelerated furnace-wall corrosions of utility boilers when using coals with Cl content of 0.3% or greater. The US experience, on the other hand, has indicated that Cl in high-Cl coals is not a major cause of corrosion of either the boiler-tubes or furnace-wall. In recent controlled laboratory studies at McDermott Technologies, Inc., tests run under simulated substoichiometric combustion conditions indicated no significant effect on the corrosion rate with variations of hydrogen chloride in the simulated flue gas. Nevertheless, because of the British data, many US boiler manufacturers have recommended a maximum Cl level at 0.3% for burning US coals. This limitation decreases the market potential of high-Cl Illinois coals. Based on the conflicting UK and US experiences in burning high-Cl coal, as well as knowledge in substoichiometric combustion, it appears that chlorine in coal may not be fully responsible, if at all, for the accelerated corrosion observed on the boiler-tubes and furnace-wall. Other factors, such as sulfidation in combination with high heat flux, may play a major role in boiler corrosion.

This is the first year of a two-year project. The overall purpose of this research is to determine the significant effect, if any, of chlorine in coal on corrosion of the furnace-wall under substoichiometric (low-NO_x) combustion conditions. The results from pilot scale combustion tests will be used to compare the corrosivity of a high-Cl (0.4 to 0.6%) Illinois coal and a low-Cl (<0.2%) Illinois coal. The comparative results will help clarify the potential effect of chlorine on furnace-wall corrosion when coal is burned under reducing/sulfiding conditions.

In order to conduct the pilot-scale combustion tests under low-NO_x conditions, modification of the Stoker boiler system at MTI was completed during the first year. A low-chlorine Illinois coal (<0.20% Cl) and a high-chlorine Illinois coal (>0.40% Cl) for the combustion tests were also chosen. In addition, the first combustion test on the low-Cl coal was completed. Samples obtained from the test were preserved and are to be analyzed in year-2 for metal corrosion and for the effects of chlorine and/or deposited ash. The second test for the high-Cl Illinois coal will be conducted in year-2. The results of these tests from combusting coal under reducing conditions will be integrated with those of our previous results from combusting coal under oxidation conditions into a data base. The established data base can be used for the boiler manufacturers to consider changing their Cl limits for burning high-Cl Illinois coals in their boilers, or can be used to benefit the utility industries and the boiler manufacturers in selecting boiler or furnace-wall construction materials.

EXECUTIVE SUMMARY

The purpose of this research is to determine the significant effects, if any, of chlorine in coal on corrosion of the furnace-wall under substoichiometric (low-NO_x) combustion conditions. The corrosivity data will be obtained from pilot-scale coal combustion tests. The corrosivity of a high-Cl (0.4 to 0.6%) Illinois coal and a low-Cl (<0.2%) Illinois coal will be measured and compared. The results obtained will help clarify the potential effect of chlorine on the furnace-wall corrosion when coal is burned under reducing/sulfiding conditions. The results of this investigation, along with those of the previous investigations, will provide data that are beneficial to the utility and coal industries and the boiler manufacturers.

Many British studies have associated accelerated fireside corrosion found on furnace-wall of utility boilers with the high-Cl content in coal (Bettelheim et al. 1980). Their corrosion data suggested that the corrosion rate of boiler tubes increased proportionately with increasing Cl concentration in coal. Based on the results of these studies, US boiler manufactures and utilities consider coals containing more than 0.3% Cl to be potentially corrosive. This 0.3% limit primarily was based on engineering studies extrapolating the British coal data to the probable corrosion behavior of US coal. The 0.3% limit on Cl level has discouraged the burning of many Illinois Basin coals in utility boilers.

A survey jointly conducted by EPRI and ICCI (Doane et al. 1994) indicated that some US utilities have had decades of experience burning high-Cl coals in the PC-fired boilers. Although fireside corrosion problems have been reported, most of them could not be directly related to the presence of Cl in coal. Furthermore, the corrosivity of two Illinois coals, one with a high-Cl content of 0.31 % Cl and the other with a low-Cl content of 0.16% was determined by Monroe et al. (1994) under pilot-scale combustion tests. The results showed that the corrosion rate of the high-Cl coal was actually slower than the corrosion rate of the low-Cl coal. In that study, resistance corrosion probes instead of conventional probes, were used in the tests, and corrosion rates were based on measurements of electrical resistance over the period of the tests. Also, during the tests for the high-Cl coal, equipment malfunctions caused higher temperature excursion which increased the relative corrosion rates. Resistance probes are particularly sensitive to short temperature increases and are also sensitive to the temperature gradients along the probes. These temperature gradients of the probes were unavoidable during the tests in both oxidizing zones and reducing zones. Though the overall results show that the high-Cl Illinois coal may not be corrosive under the test conditions, the results could not be used as a basis for redefining recommended limits of chlorine in coal for boiler combustion. This is because the data were not fully convincing due to the reasons mentioned earlier on the high temperature excursion and the sensitivity of the resistance probes subjected to temperature variations.

Our previous study (Chou et al. 1998) focused on high-temperature superheater/reheater tube wall corrosions which occurred under oxidation conditions. Pilot-scale combustion corrosion tests were conducted on a high-Cl Illinois coal, a high-Cl British coal, and a low-Cl baseline Illinois coal. The corrosion rates were measured using conventional probes under oxidizing conditions as would be experienced by superheater tube wall in a conventional boiler. The results showed no evidence of a correlation between coal Cl content and rate of corrosion, and suggested that high-Cl Illinois coals, like low-Cl coal, could be successfully used in utility boilers if other coal components or boiler properties were understood and controlled.

A recent review published by British authors (James and Pinder 1997) correlated the high-corrosion wastage observed on the furnace-wall of UK boilers with the high-Cl in UK coal. However, they also suggested that factors other than coal chlorine should be considered in the accelerated corrosion mechanism. It was suggested that the accelerated corrosion took place mainly on the furnace-wall where substoichiometric combustion and high heat flux coexisted. The presence of reducing gases implies that insufficient oxygen is supplied to the combustion zone by improper air/coal mixing, and a high heat flux dictates the existence of a high metal temperature on the furnace-wall. Under insufficient oxygen conditions, sulfur in coal is primarily converted to sulfide (H_2S) instead of sulfur oxide (SO_x). The H_2S gas is very corrosive and readily sulfidizes the conventional furnace-wall alloys. The sulfidation of the furnace-wall alloys is further escalated by a high metal temperature. Therefore, when a large H_2S concentration and a high metal temperature coexist, accelerated corrosion wastage on the furnace-wall is expected. A combination of these conditions could have accounted for the majority of the corrosion wastage experienced on the furnace-wall of UK boilers.

The conflicting UK and US experiences in burning high-Cl coal, as well as knowledge in substoichiometric combustion suggest that the role of Cl in coal on furnace-wall corrosion is not fully understood. It appears that chlorine in coal may not be fully responsible for the accelerated corrosion observed on the furnace-wall. Other factors, such as sulfidation and a high metal temperature, would also play an important role in the corrosion mechanism. In general, the smaller UK boilers may favor the formation of substoichiometric combustion conditions and flame impingement in the lower furnace, thus leading to sulfide attack at a high metal temperature.

This accelerated corrosion wastage on the furnace-wall has been experienced by some US utilities in the past few years after the implementation of low- NO_x burners (Jones 1997). By design, the low- NO_x burners create a substoichiometric combustion zone to reduce NO_x formation. While NO_x reduction is achieved, the substoichiometric combustion mechanism also generates a significant amount of H_2S in the flue gases, which can be very corrosive, and through sulfidation, it affects boiler performance. This is clearly indicated in units where medium and high-S coals are burned. These low- NO_x combustion environments would be similar to those from insufficient oxidation experienced by the UK boilers. British researchers generally believe that the presence of chlorine in the substoichiometric combustion condition would further elevate the flue gas corrosivity.

However, contrary to the general belief of British researchers, the laboratory studies by MTI (Kung et al. 1994; Kung et al. 1996) indicated that the addition of HCl to the combustion gases at a level equivalent to burning high-Cl coal under substoichiometric combustion conditions would not impose additional corrosion on the furnace-wall. In fact, the presence of HCl in the low NO_x combustion gas may retard the sulfide attack. These findings are of potential importance to the Illinois coal industry, especially the State of Illinois which has a large reserve of high-Cl coal. However, the present laboratory corrosion data available at MTI are insufficient to totally quantify the potential beneficial effect from the chlorine in coal on the low- NO_x burner applications.

The purpose of this study is to conduct pilot-scale tests using conventional probes to measure corrosion rates under reducing/sulfiding conditions as would be experienced by a water-wall in a low- NO_x boiler. The results obtained will help clarify the significance of chlorine on furnace-wall corrosion when coal is burned substoichiometrically.

The specific objectives of this study are:

- A. Acquire two Illinois coals, one containing high-Cl, 0.4 to 0.6%, and one containing low-Cl, <0.2%, and process and distribute the coals for characterization and combustion tests.
- B. Examine the nature of chlorine, sulfur, and alkali metals in coals and their roles, if any, that could affect the chemistry and mechanism of furnace-wall corrosion during combustion under substoichiometric condition.
- C. Conduct two burner-rig corrosion tests in the McDermott Technologies, Inc. (MTI) stoker boiler and collect samples for metallurgical composition and the rate of corrosion examinations.
- D. Perform metallographic examination of boiler scale and/or deposit, and measure rates of corrosion from specimen cross sections.
- E. Interpret the sampling and analysis results, and compare the rates of corrosion of the high-Cl coal with respect to the low-Cl coal.

This is the first year of a two-year project. This project is a combined effort by research teams from ISGS and MTI. ISGS has acquired coal samples, has coordinated research efforts including sample processing, distribution, and characterization, and has prepared reports for the ICCI. MTI is responsible for conducting Stoker boiler tests, analyzing the corrosion samples obtained, and interpreting the results with inputs from the ISGS.

During the first year, a Stoker boiler system at MTI has been specifically designed and modified for conducting corrosion-rate studies that can be related to substoichiometric combustion. Crown II low-Cl Illinois coal (<0.2% Cl) and Rend Lake high-Cl Illinois coal (>0.4% Cl) were chosen for the combustion tests. The combustion test on the low-Cl coal was completed during this project year. The second test on the high-Cl Illinois will be conducted in the second project year. The corrosion samples obtained from the first test were preserved and are to be analyzed after the second combustion test on a high-Cl coal is completed.

Samples obtained from both tests will be analyzed for metal corrosion and for the effects of chlorine and/or deposited ash on the rate of corrosion. The long-term corrosion rates are being measured in the boiler under identical operating conditions on the most common water-wall stainless-steel alloys for a duration (800 hours) that would give a reliable comparison. The results of this study from combusting coal under reducing conditions will be integrated with those of our previous study from combusting coal under oxidation conditions into a data base. If the data indicate that Cl in coal is not detrimental for boiler corrosion, the established data base can be used by the boiler manufacturers to consider changing their Cl limits for burning high-Cl Illinois coals in their boilers. The data obtained from these studies will also be beneficial to utility industries and boiler manufacturers in selecting boiler or furnace-wall construction materials.

OBJECTIVES

This is the first year of a two-year project which focuses on pilot-scale combustion tests to define the effect of chlorine in coal on furnace-wall corrosion under substoichiometric conditions. The goals of this project are 1) to measure the rate of corrosion of one high-Cl Illinois coal and one low-Cl Illinois coal under substoichiometric combustion conditions using conventional probes for a duration that will yield reliable comparisons, 2) to obtain concentration and occurrence data on chlorine, sulfur, and alkali metals containing compounds in coal and deposits, and 3) to help define the nature of these components and their role, if any, on the effect of chemistry and rate of corrosion under reducing/sulfiding conditions. The results obtained would help clarify the significance of chlorine on the furnace-wall corrosion when coal is burned substoichiometrically.

The specific objectives of this project are:

- A. Acquire two Illinois coals, one containing high-Cl, 0.4 to 0.6%, and one low-Cl, < 0.2 %, and process and distribute the coals for characterization and combustion tests.
- B. Examine the nature of chlorine, sulfur, and alkali metals in coals and their roles, if any, that could affect the chemistry and mechanism of furnace-wall corrosion during combustion.
- C. Conduct two burner-rig corrosion tests in the McDermott Technologies, Inc. (MTI) stoker boiler.
- D. Perform metallographic examination of boiler scale and/or deposit, and measure rates of corrosion from specimen cross sections.
- E. Interpret the sampling and analysis results, and compare the rates of corrosion of the high-Cl coal with respect to the low-Cl coal.
- D. Prepare progress and final reports, as well as presentations and publications of the results.

INTRODUCTION AND BACKGROUND

British literature correlated boiler-tubes and furnace-wall corrosion of utility boilers with the total Cl in coals and showed accelerated corrosion when using coals with Cl content of 0.3% or greater. The US experience, on the other hand, has indicated that Cl in high-Cl coals is not a major cause of corrosion. In the recent well-controlled laboratory corrosion studies at McDermott Technology Inc (formally named B&W) (Kung 1994; Kung 1996), tests were conducted under simulated low-NO_x combustion. The results indicate that the level of Cl in coal is not as harmful as predicted, and the presence of chlorine had even a beneficial effect on several stainless steels in a reducing/sulfiding environment in the temperature range of 700 to 900°F (371-482°C). These findings are of potential importance to the Illinois high-Cl coal industry. However, the present data available at McDermott Technology Inc. are insufficient to quantify the potential beneficial effect from the chlorine in coal on the low-NO_x burner applications.

This study extends the McDermott Technology Inc. test conditions to pilot-scale combustion

conditions and determines the effect of chlorine in coal, if any, on furnace wall corrosion under substoichiometric conditions. Pilot-scale combustion corrosion tests are being conducted on two Illinois coals; one with high Cl ($\geq 0.4\%$) and the other with low Cl ($\leq 0.2\%$) content. Also, conventional corrosion probes were used to measure corrosion rates over a long period of time (800 hours) which would give a reliable comparison. The results of this investigation would build upon those of the previous investigations, with the establishment of a data base, which should be beneficial to the utility and coal industries and the boiler manufacturers. If the data indicate that Cl in coal is not a factor in boiler corrosion or that Illinois coals are not as corrosive as British coals, then the results can be used as a basis for PC boiler manufacturers to consider changing their Cl limits for burning high-Cl Illinois coals. If the results indicate a similarity in corrosivity between the two coals, the data may guide PC boiler manufacturers in the selection of materials for use in boilers and furnaces designed specifically for combustion of high-Cl coals.

EXPERIMENTAL PROCEDURES

In this project the Stoker boiler facility at MTI was modified specifically for performing combustion test under substoichiometric (low-NO_x) condition. The tasks for this project, which focuses on defining the effect of chlorine in coal on furnace-wall corrosion under substoichiometric combustion conditions, were scheduled to be completed within two project years. The pilot-scale combustion test on the low-Cl Illinois, Crown II, coal was completed during the first project year, and the combustion test on the high-Cl Illinois, Rend Lake, coal will be completed during the second project year.

Task 1. Sample selection and characterization (ISGS: Year-1)

In the previous investigation (Chou et al. 1998) which determined the effect of chlorine in coal on superheater/reheater tube-wall corrosion under oxidizing conditions, Rend Lake coal and Crown II coal were used. In order to keep in continuity with the previous investigation and consultation with other members of the research team, Rend Lake coal and Crown II coal were also chosen for the current investigation as the high- and low-chlorine Illinois coals respectively. Characterization of the current coal samples was performed using traditional ASTM methods including: proximate analysis for total moisture, ash, volatile matter, and fixed carbon; ultimate analysis for carbon, hydrogen, sulfur, nitrogen, oxygen and calorific heating value; ash analysis for Na, K, etc, and total chlorine analysis.

Task 2. Procurement of 20-ton coals and coal sample characterization (ISGS: Year 1 & 2)

A low-Cl coal from the Crown II mine was provided by Freeman United Coal Mining Co., whereas a high-Cl coal sample from the Rend Lake mine was provided by CONSOL. Procurement of the Crown II coal was completed during the second half of the first project year and the Rend Lake coal procurement will be completed in the beginning of the second year as soon as the subcontract agreement between the MTI and the ISGS is established.

Subtask 2.1. Preparation and distribution of 20-ton low-Cl coal sample (ISGS/Freeman United Coal Co. Year - 1):

The twenty-ton lot of low-Cl Crown II was prepared into stoker boiler grade, between one inch and quarter inch sizes, by Freeman United Coal Mining Company. The coal sample was first screened to remove the plus one-inch material for further size reduction in a hammer mill. The size-reduced material then was screened and reprocessed, if necessary, until all of the sample was less than minus one inch. It was then remixed with the original minus one inch material.

The processed sample (roughly 20 tons) was shipped by truck to McDermott Technologies, Inc. Alliance Research Center in Ohio. One representative bucket of coal ground to -200 mesh (74 μm) was shipped to ISGS for coal characterization.

Subtask 2.2. Preparation and distribution of 20-ton high-Cl coal sample (ISGS/CONSOL: Year -2):

A high-Cl coal sample from Rend Lake mine will be provided by CONSOL for this investigation. All the procedures for sample preparation and distribution will be followed as described in Subtask 2.1.

Task 3. Advanced coal characterization with focus on the nature of chlorine, sulfur, and alkali metals in coals. (ISGS: Year 1 & 2).

Chlorine XANES analysis on coal chars from stepwise heating - Two splits of a low-chlorine Illinois coal were prepared. One split of the coal was oxidized with air and the second split of the coal was pyrolyzed under nitrogen. The weights of the coal sample were between 100g to 110g. A split of the raw coal was removed before testing. The sample was then charged into a fluidized bed reactor (FBR) and placed in the oven. A gas line and thermocouple were then connected. In the pyrolysis experiments, a second nitrogen feed was added at the top of the reactor in order to insure minimal oxygen backflow into the reactor. The gas flow was set at 1L/min and the oven was turned on. The controller was set to raise the temperature from room temperature to 200°C in one hour.

The temperature was maintained at 200°C for 30 minutes. The FBR was then opened and a sample was obtained. The FBR was closed and the temperature was raised from 200°C to 250°C in approximately 15 minutes. The temperature was maintained at 250°C for 30 minutes then another sample was obtained. This process was repeated every 50°C up to 650°C. The samples obtained were submitted to Dr. Huggins's laboratory for Cl-XANES analysis.

Chemical fractionation and ash analysis - During the four-stage serial-dissolution, inorganic constituents of the coal were isolated sequentially as water-soluble salts and loosely bound materials, exchangeable ions, acid-soluble materials, and acid-insoluble materials. The concentration of alkali metals and chlorine content in raw coals and extraction residues was determined. The amounts of alkali metals found in the water-soluble and ion-exchangeable fractions were used to account for the potentially volatile portion of alkali metals in the coal.

Task 4. Conducting two burner rig tests (MTI: Year 1 & 2)

Subtask 4.1. Conducting stoker boiler corrosion test on the low-Cl Illinois coal sample

(Year-1).

Upon receipt, the low-Cl, Crown II, Illinois coal sample was analyzed according to ASTM procedures for proximate analysis, ultimate analysis, heating value, chlorine content, major constituent analysis, and alkali content. The pilot-scale combustion test was conducted under low NO_x combustion condition. Extra effort was used to recondition the Stoker boiler by removing the extra slag build up under low NO_x combustion condition. The extra effort used more of the budget than expected, and the test was finished in a shorter time of 800 hours. The corrosion samples obtained were preserved and are to be analyzed when the second combustion test on a high-Cl coal is completed. According to McDermott Technology, the 800-hour test should be relevant in completing the goal of our project. To obtain comparable data with the first test, the second combustion corrosion test will also be conducted for a duration of 800 hours.

Samples of a furnace-wall alloy, i.e., SA213-T2, were used in the corrosion probes and exposed to the substoichiometric combustion gas. The nominal composition of T2 is given in Table 1.

Table 1. Nominal Composition of SA213-T2

Component	wt. %
C	0.1-0.25
Mn	0.3-0.61
P	0.045
S	0.045
Si	0.1-0.3
Cr	0.50-0.81
Mo	0.44-0.65

This low-alloy steel is MTI's standard material for construction of furnace walls in utility boilers. In addition, the corrosion behavior of T2 resembles that of other low-alloy steels, such as SA213-T/1 and SA2, I3-T22. Therefore, the use of T2 is ideal for the corrosion study.

A corrosion probe was designed in segment for this study. The water wall alloy T2 was machined to a tube segment with 1 inch O.D. x 1 inch length. The end of the segment was shaped to contain extruded and indented chamfers at 10° and 45°, respectively. The chamfers allow multiple segments of samples to be connected on the probe and prevent leakage of the cooling air.

Mechanical pressure was applied from both ends of the probe so that a tight fit could be achieved. Duplicate tube segments were included in the corrosion probe to obtain maximum corrosion information. Type-K chordal thermocouples were attached to one of the tube segments from inside the probe. The thermocouple junction was embedded in the tube wall through a partially drilled hole in the sample's inner surface and secured by silver soldering.

Room-temperature compressed air was supplied to the corrosion probe to maintain the

metal temperature. The air flow rate was regulated electronically by a controller which responded to the signals from the probe thermocouples. To reproduce the furnace-wall corrosion, the metal temperature was maintained at 800°F, typical for a PC-fired supercritical unit with steam temperature of 1005°F at the steam outlet.

The alloy samples obtained after the test were preserved and will be examined in year-2 as follows:

Corrosion rate measurement - Prior to the corrosion probe testing, the initial weight and outer diameter of each tube sample were carefully measured. After the 800-hour exposure in the Fireside Corrosion Testing Facility, one of the replicate T2 samples (without thermocouple) will be chemically cleaned. The chemical cleaning will remove the coal ash deposit on the sample surface as well as the corrosion scale formed during the high-temperature exposure. After the cleaning is completed, the final weight and outer diameter will again be measured. On the basis of weight change data, corrosion rates of the alloys will be calculated.

Metallographic examination- Metallographic examinations will be performed on the other replicate T2 sample (with thermocouple) after corrosion exposure. The sample will be cross-sectioned, mounted, and polished using standard Metallographic procedures. The ash deposit and scale morphologies will be examined using an optical microscope and a scanning electronic microscope (SEM) equipped with energy dispersive X-ray (EDX) analytical capability. Elemental mapping will be performed on the sample when necessary to reveal the distribution of various corrosion species. Sufficient metallographic examinations will be conducted to establish a better understanding of the corrosion mechanism and the role of chlorine in coal, if any, in the high-temperature corrosion of furnace-wall.

Analysis of coal-ash deposit- A sample of the coal ash deposit formed on the air-cooled corrosion probe will be analyzed. The purpose of this analysis is to determine the major constituents in the coal ash layer adjacent to the alloy surface which may affect the corrosion mechanism. The results of this analysis will help identify the degree of chlorine involvement in waterwall corrosion under substoichiometric combustion conditions.

Subtask 4.2. Conducting Stoker boiler corrosion test on the high-Cl Illinois coal sample (MTI: Year - 2).

After receipt, the high-Cl, Rend Lake, Illinois coal sample will be analyzed according to the ASTM procedures. The coal sample will be burned in the same test facility as in Subtask 4.1 for the high-Cl coal, and the gas and metal temperatures of the corrosion probe will be controlled to the same conditions as used in Subtask 4.1. After the test, the alloy samples will be examined according to procedures described in Subtask 4.1.

Task 5. Data collection and interpretation of results (Year 1 & 2).

All relevant technical data collected from this investigation were recorded in laboratory log books. Any instruments used for the data generation were first certified by the Instruments personnel and documented. The corrosion data will be obtained and

interpreted by MTI with technical inputs from ISGS and other members of the research team.

Task 6. Preparation of reports to the ICCI (Year 1 & 2).

MTI has served as a subcontractor to ISGS for the ICCI program. Dr. Steven C. Kung of the Corrosion section at the Alliance Research Center served as the MTI project leader and has overseen the program development. The Analytical Chemistry, Combustion Technology, and Metallurgical Technology sections at MTI are providing technical support of this program. Progress reports were prepared by the ISGS and submitted to the ICCI.

RESULTS AND DISCUSSION

Sample selection and characterization - Rend Lake coal and Crown II coal were used in our previous investigation (Chou et al. 1998) which determined the effect of chlorine in coal on high-temperature superheater/reheater corrosion under oxidizing conditions. To keep continuity with our previous investigation Rend Lake coal and Crown II coal were also chosen as high-Cl and low-Cl Illinois coals respectively for the pilot-scale combustion tests in the current investigation. The current study focuses on determining the effect of chlorine in coal on furnace-wall corrosion under reducing environment.

Characterization of the current coal samples was first performed using traditional ASTM methods including proximate analysis for total moisture, ash, volatile matter, and fixed carbon; ultimate analysis for carbon, hydrogen, sulfur, nitrogen, oxygen and calorific heating value; ash analysis for Na, K, etc, and total chlorine analysis.

Table 2. Total chlorine, total sulfur and ash content of the two coals from the prior investigation

wt % dry coal basis	Rend Lake	Crown II	Crown II*
Total Chlorine	0.44	0.14	0.10
Total Sulfur	1.22	4.48	4.77
Ash	7.90	9.38	10.29

* Data obtained from the current investigation

For the two coals selected, data obtained from the prior investigation and the current investigation on total chlorine, total sulfur, and ash content are listed in Table 2. For the Crown II coal, the analytical data obtained from the current study is very similar to those obtained from the previous investigation. Analysis of the current Rend Lake coal sample will be performed when sample preparation is completed in year-2.

Advanced analyses including x-ray adsorption near edge spectroscopy (XANES) and a serial-dissolution ash analysis on the Rend Lake coal sample were previously completed (Chou et al. 1998) and analyses of the Crown II coal sample are in progress. Analysis focuses on the association of chlorine, its availability (mobility) and occurrence (chemical association) in coal. The differences in mineralogical or chemical association of chlorine and/or mode of occurrence of alkali metals and sulfur (both organic and pyritic) in coal may

help in revealing the difference, if any, in the results from the combustion/corrosion tests.

Coal sample processing and transportation - For Crown II low-Cl coal, the twenty-ton lot of the sample was prepared into Stoker boiler grade by Freeman United Coal Mining Company. The processed sample (roughly 20 tons) was shipped by truck to McDermott Technologies, Inc. Alliance Research Center in Ohio.

Combustion tests - The pilot-scale combustion test conducted under low NO_x combustion condition for the low-Cl Crown II coal was completed in December, 1998. Extra effort was needed under low NO_x combustion conditions to recondition the Stoker boiler by removing the extra slag build up. The extra effort used more of the budget than expected, and the test was finished in a shorter time of 800 hours. The corrosion samples obtained were preserved and are to be analyzed when the second combustion test on a high-Cl coal is completed in year-2. According to McDermott Technology, the 800-hour test should be relevant in completing the goal of our project. To obtain comparable data with the first test, the second combustion corrosion test on the high-Cl Rend Lake coal would also be conducted for a duration of 800 hours. The second combustion test to be performed during the second project year will be initiated shortly after the coal is received at MTI.

CONCLUSIONS AND RECOMMENDATION

No conclusion and recommendation can be made until the corrosion samples are analyzed.

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DISCLAIMER STATEMENT

This report was prepared by Mei-In M. Chou of the Illinois State Geological Survey with support, in part by grants made possible by the Illinois Department of Commerce and Community Affairs through the Illinois Coal Development Board and the Illinois Clean Coal Institute. Neither Mei-In M. Chou or the Illinois State Geological Survey nor any of its subcontractors nor the Illinois Department of Commerce and Community Affairs, Illinois Coal Development Board, Illinois Clean Coal Institute, nor any person acting on behalf of either:

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PROJECT MANAGEMENT REPORT
September 1, 1998, through June 1, 1999

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COMMENTS

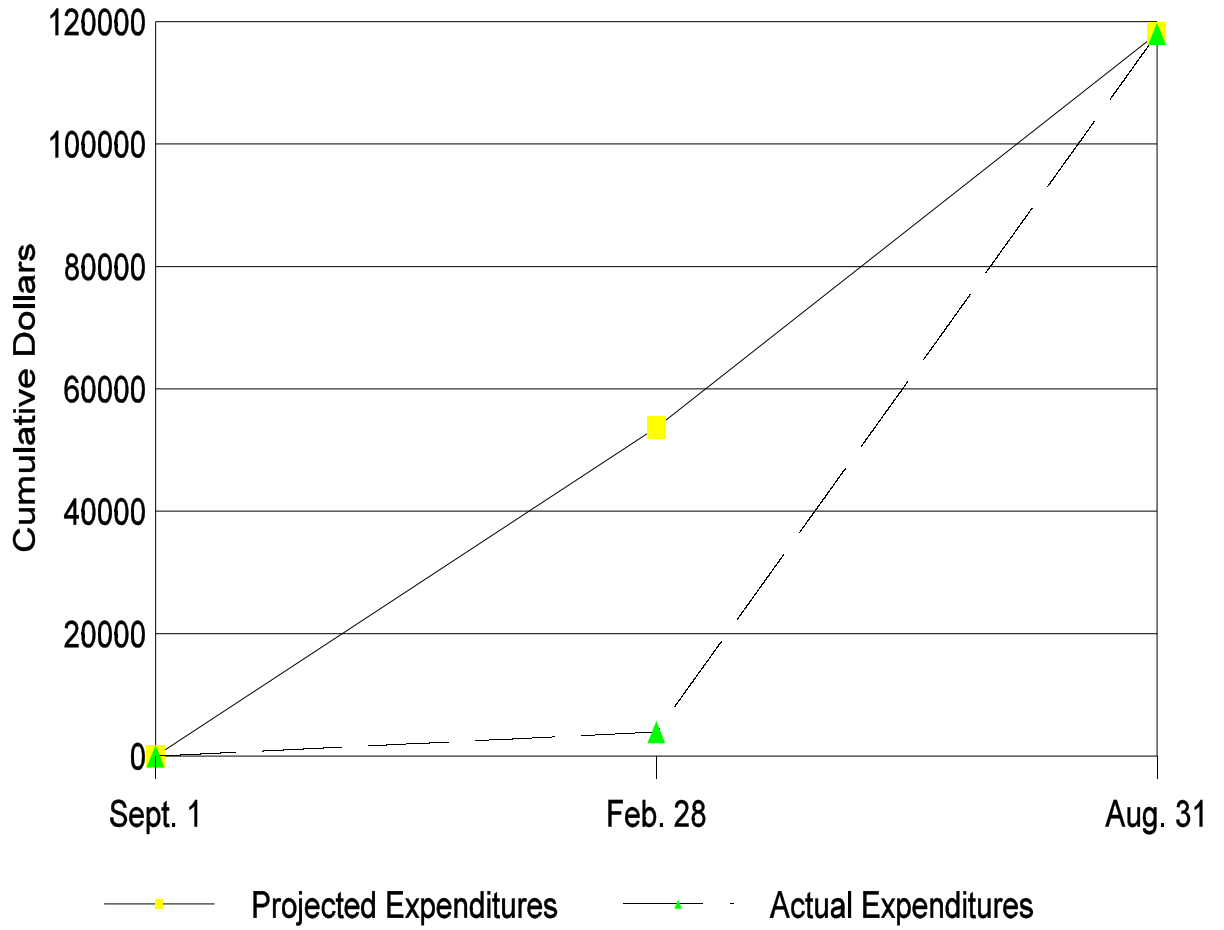
The subcontract between McDermott Technology Inc. and ISGS could not be established until the end of mid-April, 1998, because the main contract agreement between ISGS and ICCI was not received by the ISGS until the end of January 1998. Thus, the work at McDermott Technology Inc. could not begin until about nine months after the starting date of the year-1 project, September 1, 1997. A no-cost extension through June 1, 1999 was granted by ICCI to provide adequate time to complete the project accordingly. In addition, an extra effort was needed to recondition the Stoker boiler by removing the extra slag build up under low NO_x combustion conditions. Therefore, the budget for corrosion samples analyses was used for this unexpected effort. The corrosion samples obtained were then preserved and are to be analyzed in year-2 project.

EXPENDITURES - EXHIBIT B
Cumulative Projected and Estimated Expenditures

	Types of Cost	Direct Labor	Fringe Benefits	Materials and Supplies	Travel	Major Equipment	Other Direct Costs	Indirect Costs	Total
Oct. 1, 1998 to Mar. 31, 1999	Projected	10,351	1,883	2000	0	0	34,551	4,879	53,664
	Estimated	2334	502	0	0	0	649	488	3973
Apr. 1, 1999 to Sept. 30, 1999	Projected	21,357	4,010	2,000	693	0	79,239	10,730	118,029
	Estimated	21,357	4,010	2,000	693	0	79,239	10,730	118,029

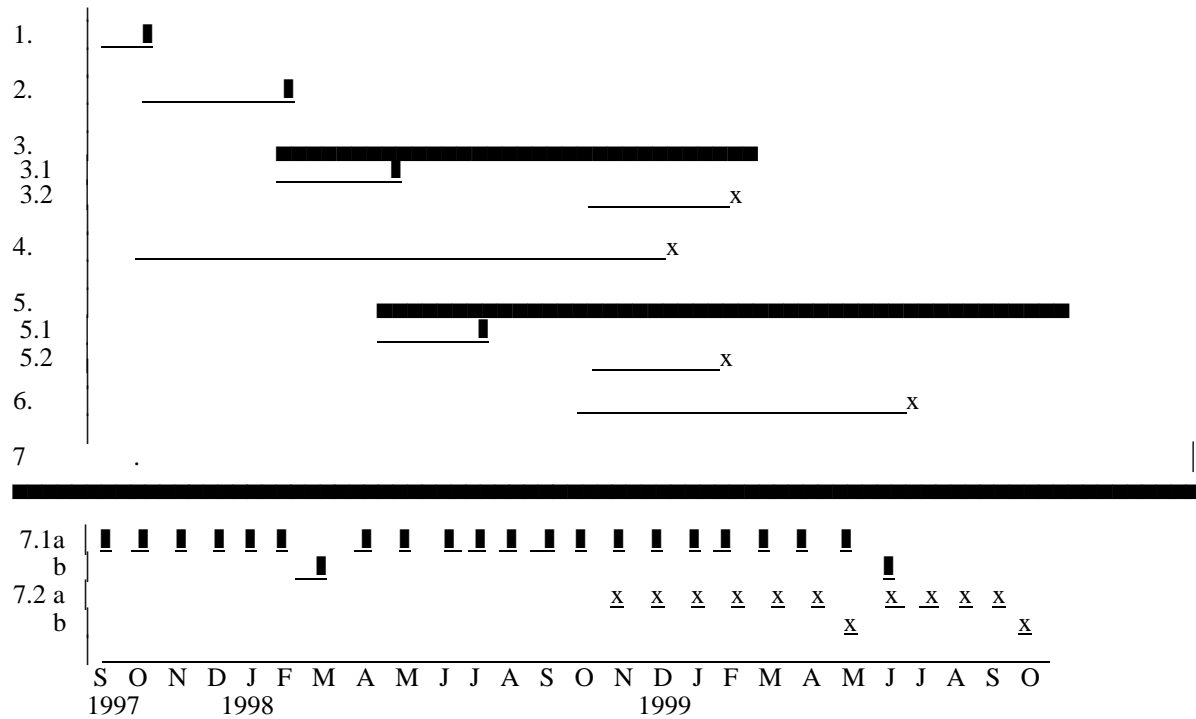
* Cumulative by Report Period

COST BY QUARTER - EXHIBIT C
Year - 2
EFFECTS OF CHLORINE IN COAL ON FURNACE
WALL CORROSION UNDER LOW-NO_x CONDITION



Total ICCI Award \$118,029

SCHEDULE OF PROJECT MILESTONES



Milestones:

1. Procurement of (bench) coal sample
2. Sample characterization and selection
3. Purchase of 20-ton coal sample
 - 3.1. Preparation and distribution of 20-ton low-Cl coal sample
 - 3.2. Preparation and distribution of 20-ton high-Cl coal sample
4. Characterization of coal
5. Conducting pilot-scale combustion tests
 - 5.1. Conducting Stoker boiler corrosion test on a low-Cl Illinois coal sample
 - 5.2. Conducting Stoker boiler corrosion test on a high-Cl Illinois coal sample
6. Data collection and interpretation of results
7. Preparation of technical and management reports
 - 7.1. a. Monthly reports and b. semi-annually, final reports to the ICCI (year-1)
 - 7.2. a. Monthly reports and b. semi-annually, final reports to the ICCI (year-2)

PUBLICATION LIST
November 1, 1997, through June 1, 1999

Project Title: **EFFECTS OF CHLORINE IN COAL ON FURNACE WALL
CORROSION UNDER LOW-NO_x CONDITION**

ICCI Project Number: 97-1/4.1B-1
Principal Investigator: M.-I.M. Chou, Illinois State Geological Survey (ISGS)
Other Investigators: J.M. Lytle (ISGS); S.C. Kung, McDermott Technology Inc.(MTI)
Project Manager: Ken K. Ho, ICCI

Chou, M.-I., J.M. Lytle, S.C. Kung, K.K. Ho, L.L. Baxter, and P.M. Goldberg. 1999. Comparative Study on the Corrosivities of High Chlorine British and Illinois Coals . Abstract. Presented to Illinois State Geological Survey Coal Advisory Board Meeting, March 8, 1999.

Chou, M.-I., J.M. Lytle, S.C. Kung and K.K. Ho, 1999. "Effects of Chlorine in Coal on Boiler Superheater/Reheater Corrosion." Preprint and paper presented to the ACS Annual Meeting in Fuel Division Symposium in Anaheim, CA, March 21-25, 1999.

Chou, M.-I., J.M. Lytle, S.C. Kung, and K.K. Ho, 1999. "A comparative study on the corrosivities derived from a British coal and an Illinois coal both with a high-chlorine content," Manuscript submitted to the Journal of Fuel Processing Technology.

EQUIPMENT LIST

November 1, 1997, through June 1, 1999

Project Title: **EFFECTS OF CHLORINE IN COAL ON FURNACE WALL
CORROSION UNDER LOW-NO_x CONDITION**

ICCI Project Number: 97-1/4.1B-1
Principal Investigator: M.-I.M. Chou, Illinois State Geological Survey (ISGS)
Other Investigators: J.M.Lytle (ISGS); S.C. Kung, McDermott Technology Inc.(MTI)
Project Manager: Ken K. Ho, ICCI

None

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